TECHNICAL EVALUATION OF MECHANISED HARVESTING OF FIELD-STACKED VINEYARD PRUNING AND SUBSEQUENT PRETREATMENT FOR SOLID BIOFUEL PRODUCTION

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ABSTRACT: This study assesses the mechanised collection of vineyards pruning residues as a low-cost biomass feedstock for advanced gasification within the CBE4I project (Clean Bioenergy for Industry). It presents the results of a field-piled vineyard pruning residues collection trial using a tractor-mounted López-Garrido TBA 2300 harvester-mulcher, with pneumatic biomass transfer to a 5 m³ front container. The performance of the collection system was satisfactory, achieving results comparable to those obtained with other commercially available machines: weight productivity of 1.47 tWM/PMH (0.85 tDM/PMH) and 0.22 tWM/ha (0.12 tDM/ha). To obtain solid biofuels the biomass was shredded using a 30 mm mesh and subsequently sieved through a 2 mm screen to reduce the fine content. The pretreatment results were 14.09 kgDM/h kW of specific mass flow and 13.56 kWh/tDM of specific energy for the shredding process. The energy consumption of the sieving process was 1.6 kWh/tDM with the mass flow rate being 43% lower than that of the shredder. The biofuels obtained fulfilled the characteristics required for the gasification tests of CBE4I project (particle size class P45, moisture content below 20%, bulk density > 200 kg/m^3, and ash content below 6%).
Keywords: biomass, harvester-mulcher, yields, agricultural residues

1 INTRODUCTION

European viticulture generates substantial amounts of lignocellulosic biomass each year in the form of pruning residues, particularly vine shoots. In 2020, vineyards in the EU covered approximately 3.2 Mha, representing around 45% of the global wine-growing area. Spain, France and Italy dominated the sector, accounting together for 74.9% of the total vineyard area and approximately 38.7% of all vineyard holdings in the EU [1]. Currently, Spain has a total vineyard area of 913,695 hectares, with Tempranillo being the predominant grape variety, accounting for 21.35% of the total surface area and covering 195,076 ha [2-3]. Despite this importance, vineyard prunings have traditionally been treated as a low-value by-product, usually shredded, incorporated into the soil or burnt in the field. The stricter field-burning regulations have led to the mechanical shredding of vineyard residues, creating a mulch layer that benefits the soil and recycles organic matter. However, this method raises operational costs and may increase pest and disease risks [4]. Their use for bioenergy therefore represents a promising option to improve resource efficiency, reduce management costs, and support the decarbonisation of rural areas and the wine sector [5-6-7].

From the perspective of resource availability, the literature broadly agrees that annual vineyard pruning can supply around 1 tDM/ha (tonne of dry matter per hectare) or more, although actual biomass yield depends on grape variety, training system, pruning strategy and interannual variability. In addition, this biomass presents energy characteristics that make it attractive for thermal applications [8]. Nevertheless, its energetic use is not without constraints. Particle-size heterogeneity, the presence of fines, and the mineral composition of this biomass, with relatively high ash contents and, in some cases, elevated concentrations of nitrogen, chlorine and sulphur, may compromise storage, automatic feeding, and combustion performance, particularly in domestic or small-scale systems [9-11].

At present, the bioenergy exploitation of vineyard prunings is mainly directed towards three pathways: their use as woodchips in medium- and large-scale boilers, their conversion into densified biofuels such as pellets and briquettes, and their integration into local cogeneration or gasification schemes linked to wineries and cooperatives. Recent studies have shown that vine shoots can be used with technical viability in medium- and large-scale biomass boilers, although appropriate control of particulate emissions and ash-related issues is required. Likewise, densification may improve logistics and fuel stability, provided that moisture content and feedstock quality are carefully controlled. More recently, self-consumption energy models in wineries have also been explored, in which pruning residues could supply a significant proportion of thermal and electrical demand [12-14]. However, the valorisation of this biomass largely depends on the technical and economic feasibility of mechanised collection, as logistics costs and energy prices are critical factors determining overall supply chain viability.

The literature generally identifies two main technological approaches: systems based on baling, and systems based on collection, shredding or chipping, and loading. The former facilitate storage and transport, although they require a subsequent conditioning stage; the latter deliver a fuel more readily usable in certain thermal applications, although it may be more sensitive to quality losses during storage. The design of harvest logistics, including collection losses, soil contamination, moisture content, storage conditions, and transport distance to the end user, remains one of the main factors limiting the large-scale implementation of these bioenergy supply chains in wine-growing regions [7,11,15]. In this context, the present study, conducted within the framework of the CBE4I project (Clean Bioenergy for Industry), assesses the mechanised collection of field-piled vineyard prunings using the López Garrido TBA 2300 equipment and their subsequent pretreatment, as a low-cost Southern

European biomass resource for feeding an innovative, highly efficient, low-emission gasification system.

2 MATERIALS AND METHODS

2.1 Study area

This study reports the results of a mechanised collection trial of vineyard pruning residues (*Vitis vinifera* L. cv. Tempranillo) conducted over 143.27 ha in a 30-year-old vineyard with a planting density defined by a 1.3 × 3.3 m spacing, located in Castillejo de Robledo (Soria, Spain) (Figure 1). Vineyards are situated within the Ribera del Duero Protected Designation of Origin, under semi-arid continental Mediterranean conditions at approximately 980 m a.s.l., on basin-derived soils typically characterised as calcareous, shallow, well-drained, with loamy-sandy to loamy-silty textures, low organic matter content, and moderate fertility [16]. The central point UTM coordinate (ETRS 89) of the study area is 41º 35' 39,4'' N 3º 29' 51,1'' W.



Figure 1: Vineyard field (left) and a pile of vineyard pruning along the farm track (right)

2.2. Biomass collection system

Biomass piles were collected using a commercial López-Garrido TBA 2300 series harvester–mulcher. The unit was operated by a Valtra T194D tractor (154 kW) adapted for forestry applications and equipped with a reverse driving position. The implement is mounted on the tractor's three-point linkage and powered by the PTO (540 rpm) together with the hydraulic system. It has a working width of 2.3 m and a cutting rotor fitted with 40 swinging hammers. The processed biomass is conveyed by an endless screw towards a turbine that pneumatically transports the material through a discharge chute into a front-mounted container (5 m³ capacity, up to 1,400 kg) (Figure 2).



Figure 2: Harvester-mulcher collecting a pile of vine shoots. López Garrido TBA 2300 equipment (left) and swinging hammers (right).

To optimize the operation of the equipment, a truck-mounted crane was required to spread the piles and adjust their height to the feeding system of the shredder (Figure 3). The containers with the collected vineyard prunings were unloaded into trucks to weigh each work cycle (Figure 4).



Figure 3: Truck with crane assisting the feeding of the shredder



Figure 4: Unloading of a container of shredded vine prunings into a truck equipped with a crane.

2.3 Solid biofuel preparation

A 90 kW pre-shredder (Silmisa Lince-45/140), with a production capacity of 1000 kg/h, was employed to reduce the particle size of vineyard pruning biomass, ensuring suitable feeding conditions and optimal performance in the gasification system. The material was fed by a hydraulic pusher (1100 mm stroke) against a single rotor (450 mm diameter, 1400 mm length) equipped with 102 integrated blades (40x40 mm), which processed the biomass through a 30 mm screen. The resulting material was subsequently sieved in a rotary screen fitted with a 2 mm mesh to reduce the fine fraction.

2.4 Experimental design

2.4.1 Biomass collection

The mechanized harvesting trial was designed to determine the following parameters: a) Weight productivity (tDM/PMH) –tonnes of dry matter per productive machine hour; b) Surface productivity (ha/PMH) –harvested hectares per productive machine hour; c) Biomass harvesting efficiency (CE, %) – calculated as the ratio between the weight of the collected biomass and the total biomass available prior to harvesting, including residual losses remaining on the ground. Operational data were obtained through the Valtra Connect telemetry system installed on the tractor, enabling continuous monitoring of working time, travel speed, fuel and additive consumption, and spatial tracking of field operations. The collected biomass was weighed using a vehicle scale at the CEDER-CIEMAT

facilities. Samples of fresh biomass (4 kg of biomass for each cleared daily polygon) were collected and sent to Laboratory of Biomass Characterization (LCB) for moisture content determination. Analytical samples were prepared according to ISO 14780, and moisture content was determined by oven-drying at 105 °C following ISO 18134-2.

2.4.2 Solid biofuel production

To obtain solid biofuels with a suitable particle size for gasification in the CBE4I pilot plant, corresponding to class P45 according to ISO 17225-9, preliminary shredding tests were carried out using 45 mm and 30 mm screens. The results indicated that the use of a 30 mm screen, followed by subsequent sieving of the biomass through a 2 mm sieve, was required to reduce the fines fraction and meet the process requirements. During the biomass pre-treatment tests, the specific mass flow and specific energy consumption of each process were recorded once the equipment reached steady-state conditions. The specific mass flow (MF, kgDM/h kW) was obtained by dividing the mass of the processed material (kgDM) by the time used to shred and sieve it (h) and by the power of the corresponding equipment (kW). To obtain the specific energy (E, kWh/tDM), the active electric energy (kWh) required by the shredder, was divided by the mass of the processed material (tDM).

2.4.3 Analytical procedures

The physical and chemical characterization of the rockrose biofuel was analyzed in the Laboratory of Biomass Characterization at CEDER-CIEMAT following the standards given Table I.

Table I: Parameters and standards applied in the physical and chemical characterization

Property	Standard
Moisture	ISO 18134-2
Bulk density	ISO 17828
Particle size distribution	Optical method (HAVER)
Proximate analysis	
Moisture	ISO 18134-2
Ash	ISO 18122
Volatile	ISO 18123
Ultimate analysis	
C, H, N	ISO 16948
S, Cl	ISO 16994
Calorific value	ISO 18125
Minor elements	ISO 16968
Ash melting behaviour	ISO 21404

3 RESULTS AND DISCUSSION

3.1 Biomass collection

Vineyard pruning residues, previously retrieved from the plots using a vine-pruning collector and subsequently arranged in piles along the field paths, were successfully collected using a harvester–mulcher system (López Garrido TBA 2300). To optimize the operation of the equipment, a truck-mounted crane was required to spread the piles and adjust their height to the feeding system of the shredder.

The collection trial was carried out satisfactorily and was positively evaluated by the landowners. The biomass collected amounted to 0.22 tWM/ha at a moisture content of 42.5 wt% w.b. (0.12 tDM/ha), with a productivity of 1.47 tWM/PMH (0.85 tDM/PMH) and a collection efficiency of 88% (Table II).

Table II: Vineyard pruning collection results: collected biomass per hectare and collection efficiency with a harvester-mulcher (López-Garrido TBA 2300)

Description	Unit	Value
Collected area	ha	143.3
Collected biomass	tWM/ha	0.22
Moisture content	%	42.5
Collected biomass	tDM/ha	0.12
Weight productivity	tWM/PMH	1.47
Weight productivity	tDM/PMH	0.85
Collection efficiency	%	88.0

tWM: tonnes of wet matter; tDM: tonnes of dry matter; PMH: productive machine hour

Table III presents results from previous experiences in the mechanised collection of vineyard prunings, covering both baling systems and comminution-based systems producing shredded material with different machinery configurations. This highlights the influence of machinery type, field conditions and residue availability on harvesting performance. In terms of productivity, the large shredder Vermeer HG6000 showed the highest values, reaching 7.1 tDM/PMH. However, this result should be interpreted with caution, as it corresponds to larger-scale equipment and to operating conditions that differ from those of more conventional vineyard machinery. If this case is excluded, the productivity values of the remaining systems fall within a more homogeneous range, between 0.64 and 0.94 tDM/PMH.

The results obtained with the López Garrido TBA 2300 harvester–mulcher are of the same order as those reported for other commercially available machines, such as the Berti PC140 shredder, a narrower and more compact machine equipped with an integrated 1.7 m³ tipping bin operating between vineyard rows (productivity of 0.84 tDM/PMH compared with 0.85 tDM/PMH for the López Garrido system). It should be noted that, in the cited study, the reported productivity refers only to harvesting and processing time, excluding bin unloading operations, whereas in the present study each working cycle included the travelling time to and from the storage point for unloading the 5 m³ container, located at an average distance of 1 km from the collected piles. This highlights the need for appropriate planning of storage point locations in order to minimise unloading trips and improve operational efficiency. On the other hand, the López Garrido TBA 2300 is a bulkier machine than the Berti PC140 and is not designed to operate between vineyard rows, requiring prior collection of vine shoots and their subsequent piling in heaps in order to work efficiently. Regarding the total amount of biomass collected, the results obtained with the López Garrido system were less favourable, reaching 0.12 tDM/ha compared with 1.06 tDM/ha for the Berti PC140. This suggests that, in the present study, the main limitation was not necessarily the operational capacity of the machine, but rather the lower availability of pruning residues and biomass losses during collection.

Table III: Previous published experiences with other vineyard pruning collection machinery

Ref	Equipment	CB	M	CB_0	P	P_0
[17]	Manually-fed chipper (Husmann H5); Greece	2.3	36.2	1.47	1.15	0.73
[17]	Large shredder (Vermeer HG6000); Spain	1.1	35.0	0.72	11.0	7.10
[15]	Modified square baler 400x300x600 mm (Lerda 900 L); Italy	2.0	44.0	1.12	1.15	0.64
[15]	Purpose-bult round baler 400x600 mm (CAEB MP 400 S); Italy	2.3	44.0	1.29	1.68	0.94
[15]	Shredder with drop-down 0.8 m^3 big-bags (Nobili (TYRP 145 RP); Italy	2.0	44.0	1.12	1.18	0.66
[15]	Shredder with a 1.7 m^3 dumping bin (Berti PC 140); Italy	1.9	44.0	1.06	1.50	0.84
-	Shredder with a 5 m^3 dumping container (López Garrido TBA 2300); Spain	0.2	42.5	0.12	1.47	0.85

CB: collected biomass (tWM/ha); M: moisture content (%); CB_0: collected dry biomass (tDM/ha); P: weight productivity (tWM/PMH); P_0: dry weight productivity (tDM/PMH)

3.2 Vineyard pruning biofuels

The biomass pre-treatment procedure applied to produce biofuels suitable for the gasification system used in the CBE4I project (P45 according to ISO 17225-9 [18]), involved under-cover storage until the moisture content decreased below 20%, followed by comminution using a 30 mm screen and subsequent sieving through a 2 mm mesh (Figure 5).



Figure 5: Sample of biomass collected with the harvester-mulcher (left) and sample of the biofuel shredded with a 30 mm screen (right) and sieved with a 2 mm mesh

The values of specific mass flow and specific energy consumption of the pre-treatment tests (shredding and sieving processes) are shown in Table IV.

Table IV: Results of vineyard pruning 30 mm shredding and 2 mm sieving processes

Description	Unit	Average value
Shredding (30 mm)		
MF	kgDM/h kW	16.91
P	kW	90
F	tDM/h	1.52
E	kWh/tDM	14.24
Moisture content	wt.% (w.b.)	10.8
Sieving (2 mm)		
MF	kgDM/h kW	580.44
P	kW	1.5
F	tDM/h	0.87
E	kWh/tDM	1.60
Moisture content	wt.% (w.b.)	10.3

MF: specific mass flow; F: equipment flow; E: specific energy; tDM: tonnes of dry matter

When comparing the results obtained from vineyard pruning shredding with those achieved using the same equipment for other agricultural pruning residues, such as olive tree prunings [19], vineyard prunings showed a higher specific mass flow (16.91 versus 14.0 kgDM/h·kW) and a similar energy consumption (14.24 versus 14.5 kWh/tDM). It should be noted that, when the sieving process was implemented as a continuous operation downstream of the 30 mm shredding stage, the overall efficiency of the pre-treatment process in the pilot plant used decreased by 43%. To avoid the need for sieving, collection operations should preferably be carried out under dry field conditions in order to minimise soil contamination of the biomass and preserve its quality for biofuel production.

The physical and chemical characterization of the biofuels obtained is shown in Tables V and VI. The conditioning processes enabled the material to meet the required fuel quality specifications, including a particle size distribution with 60 wt% of the biomass within the 3.15–45 mm fraction (Figure 6), a bulk density above 200 kg/m³ and an ash content below 6%

The produced biofuel exhibited 5.7% ash (>3% to be classified as I1 according to ISO 17225-9), so it can be classified as class I3 for industrial use, that allows ash content ≤ 6%. It should be noted that the vineyard pruning collection was conducted after a rainy period, possibly promoting the uptake of soil minerals by the biomass during harvesting, what contributes to the increase in the ash content of the biomass. On the other hand, the nitrogen content exceeds the 0.5% limit established for class I; therefore, according to the standard cited above, it could be classified as I2 or I3 for industrial use. The trace element content is very low, including copper, which can be elevated due to the application of copper salts as herbicides. Moreover, no slag formation problems are expected, since the deformation temperature exceeds 1200 °C (Table VI) and the fluid temperature is 1450 °C.

Table V: Basic characterization of collected vineyard pruning (VP) with the harvester-mulcher and after pretreatment processes (milled to 30 mm and sieved to 2 mm)

Parameter	Unit	Collected VP	Pretreated VP
Moisture	wt.% (w.b.)	11.8	10.3
Bulk density	kg/m^3 (w.b.)	100	200
Ash content	wt.% (d.b.)	6.0	5.7
NCV	MJ/kg (w.b.)	15.27	14.94
NCV	MJ/kg (d.b.)	17.21	17.16

NCV: net calorific value; wt.%: weight %; w.b.: wet basis; d.b.: dry basis

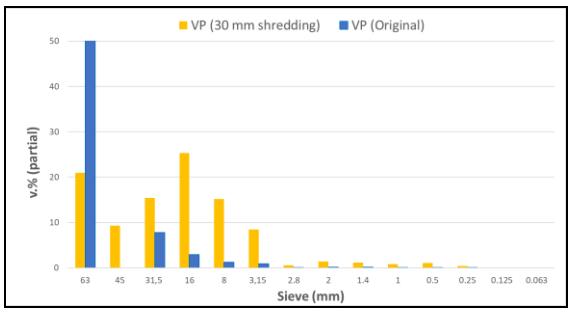


Figure 6: Particle size distribution of the vineyard pruning with or without shredding (v.% partial on the sieve)

Table VI: Physical and chemical characterization of vineyard pruning biofuels (VP) after pretreatment processes (milled to 30 mm and sieved to 2 mm)

Parameter	Unit	VP biofuels	ISO 17225-9 (I1 class)
Moisture	wt.% (w.b.)	11.3	≤ 45
Bulk density	kg/m^3 (w.b.)	200	NA
Calorific value:			
NCV	MJ/kg (d.b.)	17.16	NA
NCV	MJ/kg (w.b.)	14.94	NA
Ash content	wt.% (d.b.)	5.7	≤ 3
Ultimate analysis:			
Carbon	wt.% (d.b.)	48.7	NA
Hydrogen	wt.% (d.b.)	5.7	NA
Nitrogen	wt.% (d.b.)	0.62	≤ 0.5
Sulphur	wt.% (d.b.)	0.04	≤ 0.05
Chlorine	wt.% (d.b.)	<0.01	≤ 0.05
Minor elements:			
As	mg/kg (d.b.)	0.1	≤ 1
Cd	mg/kg (d.b.)	<0.01	≤ 2.0
Cr	mg/kg (d.b.)	3	≤ 20
Cu	mg/kg (d.b.)	5.7	≤ 30
Hg	mg/kg (d.b.)	0.008	≤ 1.0
Ni	mg/kg (d.b.)	1.5	≤ 10
Pb	mg/kg (d.b.)	<0.2	≤ 10
Ash melting behaviour:			
SST	°C	1170	NA
DT	°C	1280	NA
HT	°C	ND	NA
FT	°C	>1450	NA

NCV: net calorific value; wt.%: weight %; w.b.: wet basis; d.b.: dry basis. SST: shrinkage staring temperature; DT: deformation temperature. HT: hemisphere temperature. FT: fluid temperature. ND: Notdetected. NA: not applicable.

4 CONCLUSIONS

The mechanized collection of vineyard prunings, as a low-cost Southern European biomass resource, using the harvester-mulcher equipment was demonstrated to be technically feasible under the operational procedure implemented, achieving productivity levels comparable to those reported for other commercial equipment, around 0.85 tDM/PMH.

The applied pretreatment enabled compliance with the biofuel quality requirements, such as ash content (< 6% d.b.) or particle size (P45), for its use in the gasification pilot plant of the CBE4I project.

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7 LOGO SPACE



